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# INVESTIGATION OF GATING PARAMETERS, TEMPERATURE AND DENSITY EFFECTS ON MOLD FILLING IN THE LOST FOAM CASTING (LFC) PROCESS BY DIRECT OBSERVATION METHOD

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## Abstract

Mold filling sequence of A356 aluminum alloy was investigated with the aid of direct observation method (photography method). The results show that increase of the foam density causes decrease of the filling rate and increase of the filling time. Foam density has more pronounced effect on mold filling rate rather than pouring temperature. Gating design also affects the profile of molten metal advancement in the mold. The results show that the higher filling rate was obtained with G2 gating than with other gating system. Regarding the mold filling pattern, G3 gating system has more effective contact interface than G2 gating system and has lower filling time. Filling time in G4 gating and G1 gating system are nearly the same.
*Key words: LFC, Mold filling, Aluminum, Photography, Foam density, Pouring temperature, Gating system*

## Introduction

Application of foam pattern for producing production of castings part was originally patented by H.F.Shroyer in U.S in 1958 [1]. During these years many works were done to improve and make this process better ad reliable. Recently, this process was used to produce parts like cylinder, head cylinder and complex parts without using of cores and with parting line elimination [2]. In the lost foam casting (LFC) process the pattern was is made in desired shape from proper foam, then sprue and gating system are assembled. Prepared foam clusters are usually coated with refractory coating by dipping, spraying or other methods. The coated cluster is placed in a flask and backed

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up with unbounded sand. The sand compaction is achieved by a vibration table. After sand compaction process the molten metal is poured into the mold. In the LFC process, during the pouring of the molten metal, the heat of molten metal causes the decomposition of foam pattern transforming it to degradation products in the form of liquid or gas [3]. For successful filing, these foam degradation products must be completely eliminated through the coating outside of the mold. It is generally believed that for solving the problem related to LFC process needs the understanding of the foam degradation mechanism and method of this decomposition products elimination. There are many works on these issues [4-9]. Investigation of mold filling in LFC process could be done with different method and generally they can be divided in two distinct categories: direct observation and indirect observation. In direct observation, a Pyrex glass is used as one of the mold wall. The filling process is recorded by using a digital camera and then captured film is used to analyze the mold filling mechanism [10-13]. Unlike conventional casting when mold filling is restricted by gating system, in lost foam casting mold filling rate is controlled by foam degradation rate. On the other hand, foam degradation rate is affected by some parameters such as coating permeability, pattern geometry, pouring temperature, molten metal type, type of coating and its thickness, density and surface condition of used foam, vacuum, sprue height [5,6,8,14-18].

In this research the effects of temperature and foam density and gating design on mold filling mechanism of A356 aluminum alloy are investigated.

## Experimental

Pattern with dimension of 120×120 table 10 mm was cut from expanded polystyrene (EPS) block with densities of 10, 15 and 20 kg/m$^3$ was used for investigation of the effect of foam and temperature. Patterns with density of 20 kg/m$^3$ were used to investigate the effect of gate placement effects. Gating system with the same effective metallostatic head pressure was assembled to the pattern with hot melt glow. Pattern dimensions and different gating system are shown in Figure 1.

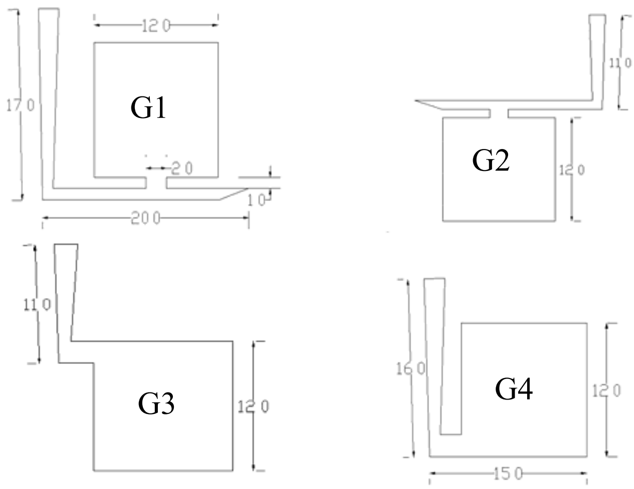



*Fig1. Pattern dimension for different gating system, all dimension are in mm.*

Prepared cluster was coated with graphitic refractory coating (styromol 702 FM) with thickness of 0.5 mm. The thickness of coating was measured by weighting a pattern before coating and after drying. Coated pattern was dried in air for 24 h at room temperature. The pattern has two sides. One side is coated and another one will be remain uncoated. The uncoated side was glowed to the Pyrex glass. This pattern which will be at the front of the move camera was placed in flask in dimension of 270×270×270 mm and during sand filling flask vibrated with vibration table to compact unbounded sand. Duration of compaction cycle was 1 min. Melting of A356 aluminum alloy was performed in electrical furnace. To investigate the effect of temperature and foam density on the filling rate, the pouring temperature was varied from 700-760 ºC with a step size of 30ºC. To investigate the effect of gate placement on filling rate, the pouring temperature was kept at 730ºC. During pouring process in order to secure the constant pouring rate, pouring basin was blocked by a piece of graphite until it became full and then after releasing it molten metal flew to the mold. Thereafter with addition of molten metal, pouring basin remains full. During mold filling the mold filling sequence was recorded by a digital camera. This method is schematically shown in Fig.2. Films were analyzed with the extraction of the frames.

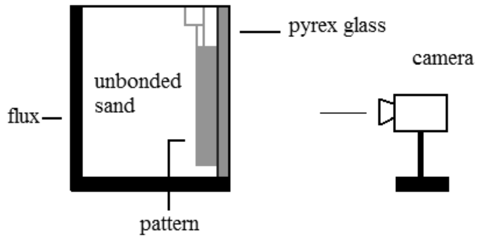



*Fig 2. Schematical figure of direct method observation.*

## Results and discussion

Foam density and temperature effects

To investigate the effect of foam density and pouring temperature the G1 pattern was used (see Fig.1). Fig.3 shows the effects of foam density and pouring temperature on the filling time.

According to the results from Fig.3, when the pouring temperature was kept constant, with increasing of the foam density, mold filling time increases and mean velocity of mold filling decreases. It seems that with increasing the foam density the amount of heat for pattern degradation increases and causes the decrease of temperature of the molten metal at interface that decreases the mold filling rate. Also, with increasing foam density the degradation products in the front of the advanced molten metal increase which can exert a back pressure on the front of the advanced molten metal restricting the movement of the molten metal.

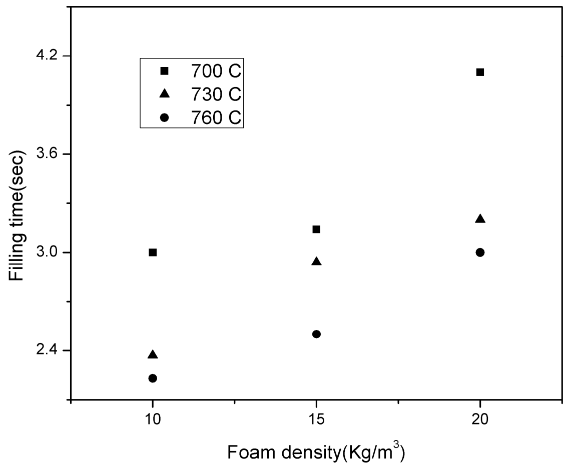



*Fig 3. Density and temperature effect on filling time.*

Fig.4 shows the effects of foam density and pouring temperature on the mean filling velocity.

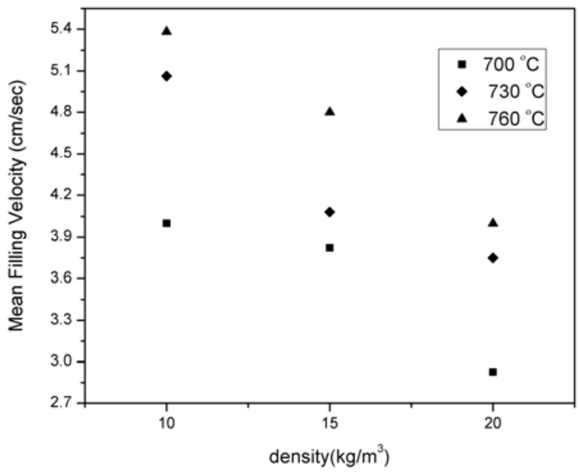



*Fig 4. Density and temperature effect on mean filling velocity.*

Fig.5 shows the mold filled volume of G1 gating system during pouring vs. time. As can be seen the mold filling process could be divided to three distinct sequences: the slow start, accelerating and finally decreasing end state. The slow movement of the molten metal at the beginning could be related to the lower foam degradation rate due to small quantity of molten metal entering the mold. As the amount of the molten metal in the mold increases the molten metal-foam pattern interface increases causing higher extent of foam degradation which accelerates filling rate. Finally, due to decreasing state in metallostatic pressure in G1 gating system the filling rate decreases at the end stage.

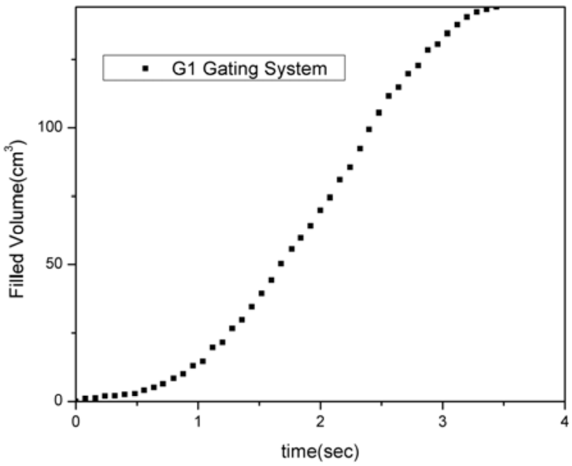
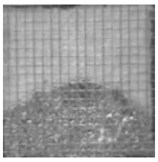
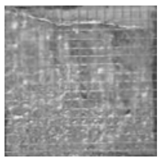
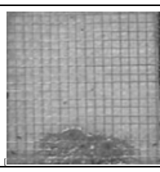
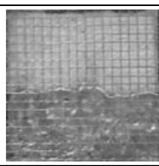
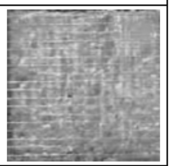
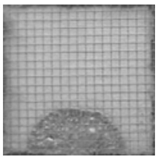
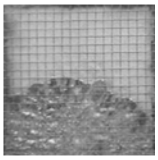
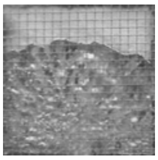
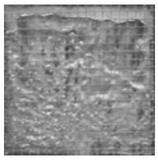
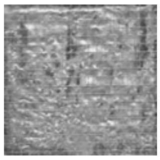



*Fig 5. Filled volume in G1 gating system, foam density 20 kg/m3, pouring temperature 730$^o$C.*

Fig 6 shows the mold filling sequences of the selected experiments. As can be seen, increasing the pouring temperature increases the mold filled volume in the same time step. The time step is 0.5 second. This can be attributed to the faster degradation of the foam pattern due to more superheat of the molten metal which accelerates the foam degradation.

| | 0/5s | 1s | 1/5s | 2s | 2/5s |
|---|---|---|---|---|---|
| Foam density= 10 kg/m$^3$ Pouring Temp= 700$^o$C |  |  |  |  |  |
| Foam density= 10 kg/m$^3$ Pouring Temp= 730$^o$C |  |  |  |  |  |
| Foam density= 10 kg/m$^3$ Pouring Temp= 760C$^o$ |  |  |  |  |  |

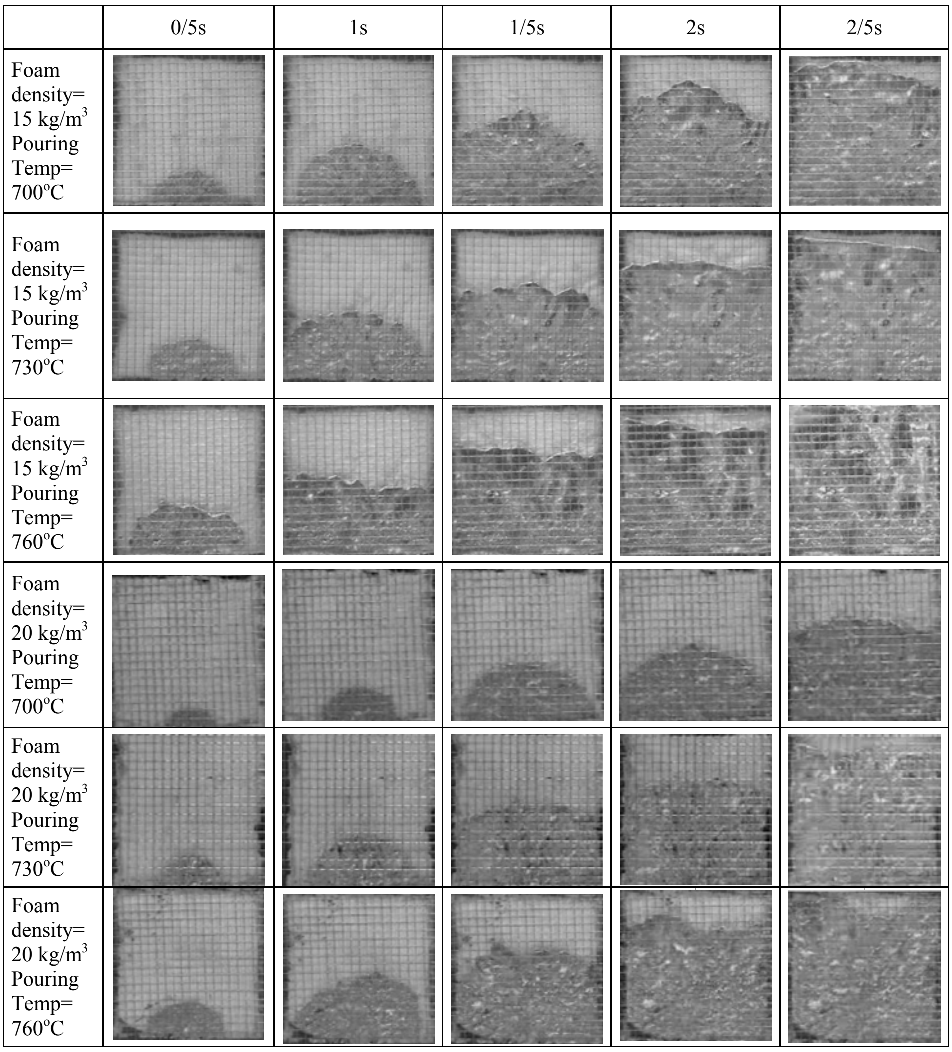



*Fig. 6 Mold filling sequence in G1 gating system (density and temperatures effects).*

As can be seen in Fig.6, there is no visible gap between advancing molten metal and degrading pattern. It means that the molten metal progresses with the rate of pattern degradation. However, any rupture during pouring may cause formation of a gap between advancing molten metal and pattern due to heat radiation. In this situation if the coating could not sustain against the unbind sand, unbound sand will flow into the mold and mix with molten metal. It should be emphasized that the continuous pouring during casting is essential parameter in LFC process.

Fig 7 shows the gap formation during pouring when pouring was suddenly ruptured.

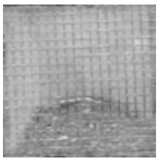
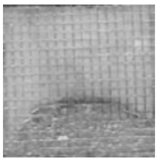
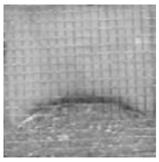
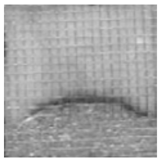
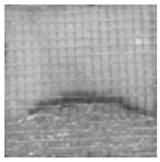
| | 2s | 2/5s | 3s | 3/5s | 4s |
|---|---|---|---|---|---|
| Foam density= 20 kg/m$^3$ Pouring Temp= 700$^o$ C |  |  |  |  |  |

*Fig.7. Gap formation during suddenly ruptured pouring.*

*Effect of gating system type*

To study the effect of gating system on filling rate, experiments were done with different gating systems, but in constant effective metallostatic head pressure. Foam density and pouring temperature were kept constant at 20 kg/m$^3$ and 730 ºC, respectively. The results of gating placement effect on mold filling time and average filling velocity are shown in Fig. 8 and Fig.9, respectively. The results show that top gating systems have higher filling rate that is related to the increasing metallostatic pressure during mold filling for these systems compared to decreasing state in other systems. This increasing pressure caused by molten metal weight can exert an extra force to pattern degradation products to escape from mold through the coating. Consequently, it causes more increase in filling rate of mold in G2 and G3 gating systems.

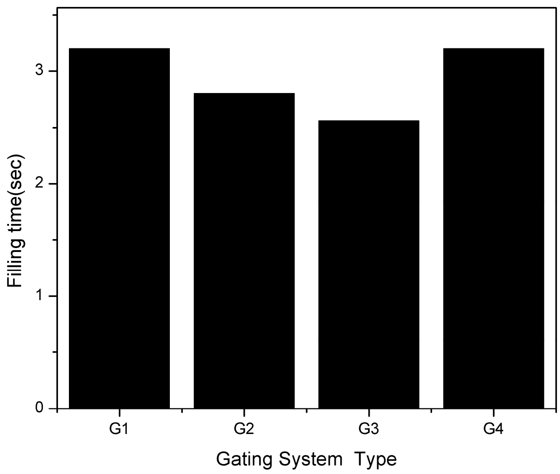



*Fig. 8. Filling time in different gating systems.*

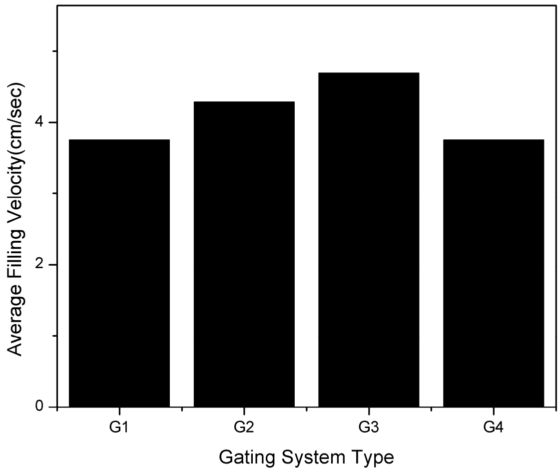



*Fig. 9. Average filling velocity in different gating systems.*

Fig.10 shows the mold filled volume of G1 and G2 gating system during pouring vs. time. Like G1 gating system, G2 gating system have low filling rate in the first stage due to low interface between foam and entered molten metal. With increasing of the amount of the molten metal in the mold, foam-molten metal interface increases causing the acceleration of the mold filling rate. However, unlike G1 gating system, in gating system G2 filling rate does not change excessively at the end of filling stage due to increasing metallostatic head pressure at the top of gating system.

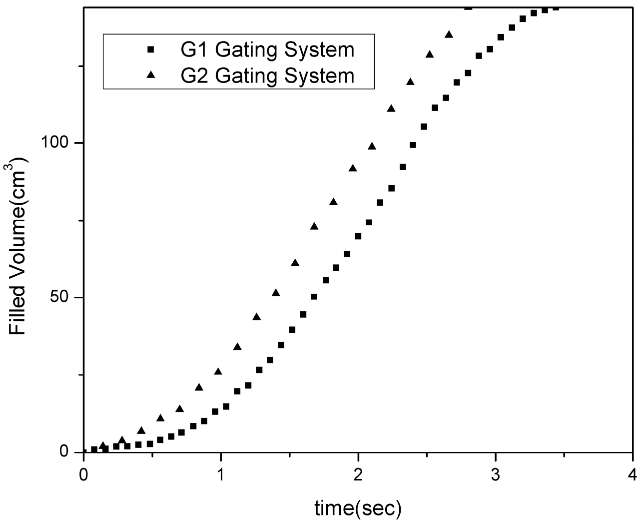



*Fig 10. Filled volume in G1 and G2 gating systems, foam density 20 kg/m$^3$, pouring temperature 730$^o$C.*

There are two different systems in top gating systems. In G2 gating system, filling time is lower than in G3 gating system. It seems that differences between filling time of G2 and G3 gating systems are related to the advancing manner of molten metal movement through the mold which is shown in Fig. 11. As can be seen from Figure 11, G3 gating system has more developed metal-foam interface during the filling. This can lead to increase in foam degradation velocity.

Unlike conventional casting like sand casting process existence of foam pattern in the mold, make mold filling so different from conventional top gating empty mold. In top gating lost foam casting process, for low melting temperature alloys like Al alloys, the molten metal will be controlled by the foam degradation and molten metal will flow gradually from up to down. Also the mold filling process will be without any turbulence that always appears in sand casting process for top gating system.

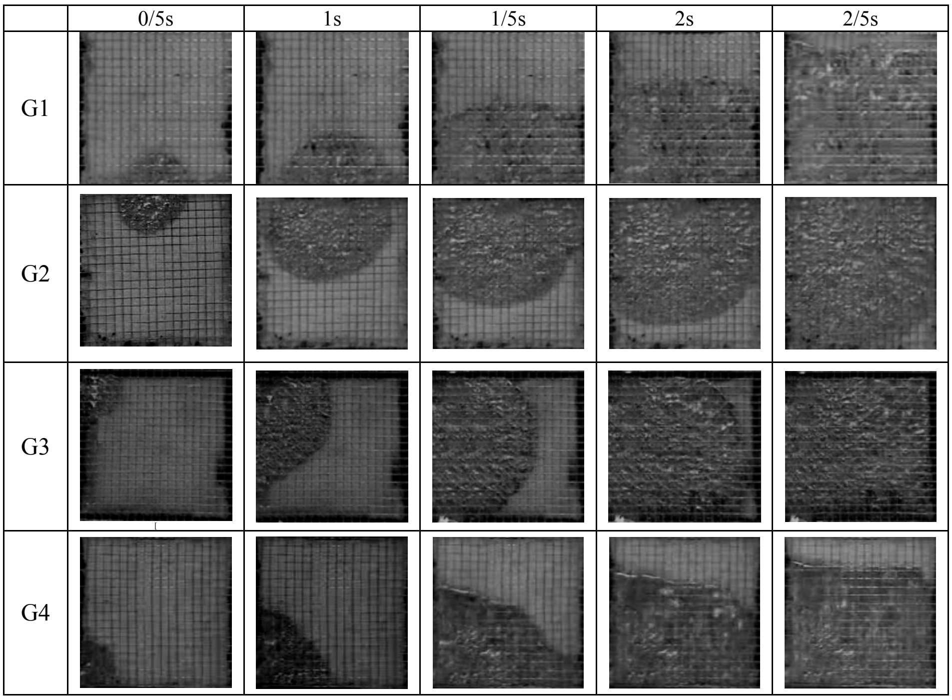



*Fig. 11. Mold filling sequence in different gating systems at 730$^o$C pouring temperature and 20 kg/m$^3$ foam density.*

## Conclusions

The following conclusions can be drawn from this study:

When the foam density increases the filling time increases due to increase in foam degradation products. Foam degradation products exert a back pressure on the molten metal interface causing the decrease in mold filling rate and time.

Foam density has more pronounced effect on filling rate than pouring temperature.

Increasing pouring temperature increases the filling rate.

Filling rate was also affected by gradually increase in metallostatic head pressure

The filling rate at the top of gating system is higher than at the bottom of gating system. This behavior may be related to the gradual decrease in metallostatic head pressure at the bottom of gating systems.

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